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Highlights

- Between 1 and 12 km, the modal share of electric and folding bicycles increases slightly.
- The performance of electric two-wheelers is worse for sulphur dioxide emissions.
- The emissions of electric two-wheelers can be improved by choosing renewable energies as the source of electricity.

Abstract

This study aims to analyse the factors and strategies that condition the bicycle's use and highlight various unknown facts about the electric bicycle. To identify the brakes (examples: road safety, urban culture or social norms) on the use of the bicycle and the possibilities of modal shift, a survey was carried out within three main campuses at the University of Liege (ULg) in Belgium. A brief presentation of the main routes and the description of the route most taken (based on cartographic identification, a field visit and interviews) complete the survey results. During this study, 29,000 people (students, doctoral students, and staff members) were contacted to participate in the survey. The results of this work show that despite the topographical conditions of the city studied, a priori unfavourable, and some major obstacles, such as the lack of cycle paths and road insecurity, or the price in the case of the electric bicycle, the potential for a modal shift towards cycling, and particularly towards electric bicycles, is great. 70 % of respondents live less than 12 km from the University, a distance considered the limit for travelling by electric bike. Mitigating these brakes is a priority to stimulate modal shifts. The study of the image of the bicycle and the perception of the brakes shows that better communication could avoid erroneous evaluations as to the possibility of travelling by bicycle. Analysis of the profile of respondents reveals that contrary to the data in the literature, students represent the public least attracted to cycling. Initiating a modal shift to obtain a mass effect is therefore essential. One of the most important factors in pursuing a modal balance is the development of safe cycle paths, where a potential increase in bicycle use is recognized by 62 % of car users, 82 % of bus, 62 % of staff and 74 % of students. Finally, some paths are suggested to improve the downtown-rural cycle route and promote the use of bicycles in the university community.

Keywords : Big data, Bicycle, Sustainable cities, Transition

1. Introduction

In most developed countries and newly industrialized countries, the growing use of private cars is causing many environmental, social, and economic problems (IEA (International Energy Agency), 2009). Sustainable development is more than ever at the heart of current concerns, new solutions aimed at ecological, socially inclusive, and economy-promoting mobility must be developed (IEA (International Energy Agency), 2009). Among many possible solutions, we have chosen for this work to focus on the bicycle – both classic and electrically assisted – as a mode of transport. The literature mentions that nowadays, the transport sector accounts for more than 26 % of the energy consumed in the world (Hammer et al., 2011). In addition, in recent years, greenhouse gas emissions and energy demand in the transport sector have increased faster than for any other sector, energy demand has more than doubled between 1990 and 2020 (Kahn Ribeiro & Kobayashi, 2007).

From an economic point of view, dependence on oil also makes our society very vulnerable to energy crises (Vandenbulcke et al., 2011). The widespread use of private car also creates significant congestion problems in cities, involving loss of time, overconsumption of fuel, and economic impacts (Hammer et al., 2011; Kahn Ribeiro & Kobayashi, 2007). Globally, car congestion increased by 13 % between 2008 and 2015 (Kahn Ribeiro & Kobayashi, 2007). Traffic congestion occurs when a volume of traffic or modal split generates demand for space greater than the available street capacity; this point is commonly termed saturation. In 2015, the car congestion rate in Brussels was 35 %, which means that commuters have to plan on average 35 % more time for their journey (Le Vif/L'Express, 2016). In Liege, the car congestion rate was 21 %, a figure that has increased significantly in one year, since it was 17 % in 2014 (Le Vif/L'Express, 2016). For some authors (Dober, 2000; Shoup, 1997), however, it is the space required for car parks that is the most problematic. Although already significant, this space is nevertheless insufficient in many places. In large cities, up to 10–20 % of traffic is due to the search for parking (Cools, 2015).

Cycling is known as a “green” mode of transport that does not emit CO_2, does not consume energy, and also does not pollute the air. Cole-Hunter et al. (2015) explained that high bicycle use would help reduce pollution and high oil dependency. Héran (2012) explained that the cost of building a bicycle car park is almost 50 times less than that of a car park. Free space for one vehicle is equivalent to mini parking for up to eight bicycles. The bike is silent and therefore emits no noise pollution. It is also affordable for most households and accessible to most people, especially young people, who cannot drive a car. Most e-bikes on the European market are identical to a conventional bike at first glance because the components are integrated into the design of the bike. The motor is only approximately 15 cm in diameter and is mounted on the hub of the front or rear wheel or the crank set, while the battery can be integrated into the rack or along with the frame (Ji et al., 2014).

In Belgium, CO_2 emissions linked to transport represent more than 20 % of total emissions, and therefore we must invest massively in the infrastructure of soft mobility if we want to succeed in the climate transition. Globally, 88 % of Belgians have a car, while the 30 % have at least two. Only 3 % of households have an electric or hybrid vehicle. LPG accounts for 1 % of the car fleet. So, gasoline cars represent 50 % of the car fleet, whereas 46 % of cars have a diesel engine (Lorenzo Stefani, 2019).

Interesting studies on the benefits of cycling, the obstacles to its use, the promotion methods, etc., have already been performed (Weinert et al., 2008; Weinert, Ma, Yang, & Cherry, 2007; Weiss et al., 2015; Whitmarsh & Kohler, 2010). Its sustainability as a mode of transport no longer needs to be demonstrated (Wilkinson, 1997; Winters et al., 2010). It is, however, clear that in Wallonia, the number of cyclists remains extremely low. A more rugged terrain than in the north of the country and an undeniable lack of cycle paths hinder the use of bicycles in this region (Wolf & Seebauer, 2014; Woodcock et al., 2007).

Schools are often considered to be one of the sectors with the greatest number of employers in most developed countries (Bachand-Marleau et al., 2012). Therefore, to reduce the rate of CO_2 emissions, most of these schools adopt a common policy to implement strategies to reduce dependence on individual cars and encourage the proliferation of common transport or bikes (Rotaris & Danielis, 2015). In addition, schools appear to be more favourable environments for the use of sustainable modes of transport.

The main objective of this research is to identify and propose strategies to encourage the mode of travel by bicycle in urban areas. Under this basis, a case study linking the two main campuses of the University of Liege was conducted. The different opportunities related to the use of conventional and electric bicycles used daily for commuting and home-school are discussed. In Section 3 of this study, a survey was conducted during which 29,000 questionnaires were distributed to many students and staff members of the University of Liege. An analysis and comparison of the results are detailed in Section 4. The main idea of this research was to encourage the large-scale use of conventional and electric bicycles to limit the heavy expenditure on fossil fuels in the transport sector. In summary, our research revolves around three main questions:

- To what extent is the bicycle appreciated as a mode of transport by the university population, what are the obstacles that prevent its use, and how are these obstacles perceived? This first part seeks to collect the opinions of the university population concerning the bicycle as a mode of transport.
- To what extent do the geographical and topographical situation of the city and the urban and architectural characteristics of the cycle paths allow the use of conventional and electric bicycles as a mode of transport for the residence-ULg trip? This section includes the identification of residence-ULg courses in terms of distance and elevation, and the analysis of the characteristics of the main courses from an urban planning and architectural point of view.
- How to promote the use of bicycles for travel between residence and ULg? This more strategic component attempts to identify the most effective and appropriate ways to stimulate a modal shift towards cycling.

2. Literature review

According to Langford et al. (2015) in recent years, the electric bicycle has emerged as a new mode of active and sustainable transport. According to Cherry et al. (2016) in the history of motorization, it is the alternative mode of transport to the petroleum which had the fastest adoption. According to Weiss et al. (2015), the first electric two-wheelers emerged in China in the early 1980s. According to Weinert, Ma, and Cherry (2007) at that time, their high price and poor battery performance prevented them from entering the market on a large scale. According to Zhen et al. (2006), it was not until the late 1990s that electric two-wheelers entered the market in southern China, and in just a few years their popularity spread throughout the country. Sales began to grow exponentially according to Ji et al. (2012). According to Astegiano et al. (2015) currently, China is the leader in the electric bicycle market. Weinert, Ma, and Cherry (2007) stated that the majority of electric two-wheelers are concentrated there in China.

In China, the electric bicycle has grown faster than any other mode of transport, stated Liu et al. (2015), with an annual growth rate of 54 % on average between 1998 and 2013 CNLIC (2013), reaching up to 86 % Ji et al. (2012). For 15 years, the production of electric bicycles has multiplied by 60. In many Chinese cities, there are currently more e-bikes than conventional

ones (Zhen et al., 2006). In recent years, new small but growing markets have been observed in other Asian countries (Japan and India), Europe (mainly the Netherlands and Germany), the United States, and Australia. According to Popovich et al. (2014), in these markets, the type of two-wheeler sold is almost exclusively electric. According to Dozza et al. (2015) in Europe, e-bikes have been available on the market for more than a decade but it is only very recently that their numbers have started to increase. Weiss et al. (2015) stated that in 2013, 5 % of bicycles purchased were electric, and the sale of electric bicycles accounted for 2 % of the global market. Germany and the Netherlands alone account for two-thirds of sales in Europe.
In the Netherlands, 20 % of bicycles purchased are electric, said COLIBI and COLIPED (2014). Belgium seems to be the next largest market as claimed by Weinert, Ma, and Cherry (2007). Popovich et al. (2014) explained that while the use of e-bikes is increasing worldwide, it is China that has experienced the most dramatic growth since the late 1990s, and it is worth studying the reasons. The study of the history of the electric two-wheeler market in China shows that this spectacular growth is mainly related to political decisions.

2.1. Private car problems

Shannon et al. (2006), explained that over the last century, the car had become an essential component of our society. While this has brought innumerable advantages in terms of comfort, for example, the majority of developed countries today face many environmental, social, or economic problems due to the widespread use of the automobile (Vandenbulcke et al., 2009) and it is commonly accepted that our transport systems are not sustainable (United Cities and Local Governments, & Cities for Mobility, 2009). Unlike other sectors (residential, commercial or industrial) which have relatively varied energy sources, the transport sector depends almost exclusively on fossil fuels: only oil accounts for 95 % of the energy used for transport in the world, making it one of the sectors with the most harmful effects on the environment (Figueroa et al., 2014). The transport sector is responsible for 28 % of the world's CO_2 emissions (this figure rises to 30 % if we only consider OECD (Organization for Economic Co-operation and Development) member countries), and 74 % of these emissions come from road transport (Figueroa et al., 2014; Hammer et al., 2011). In the Europe 27.26 % of greenhouse gas emissions from private households were due to transport (IEA (International Energy Agency), 2009; Hammer et al., 2011). The transport sector accounts for 28 % of the energy consumed worldwide (IEA (International Energy Agency), 2009). According to Cooper et al. (2003), car addiction is harmful to human health. It is first of all one of the causes of physical inactivity. Frank et al. (2004) notably found a positive association between obesity and time spent in the car.

2.2. Bike mobility in Belgium

The electrification of modes of transport has emerged in recent years as a widely supported strategy with to reduce the problems associated with dependence on the automobile and the combustion of oil. More specifically, the electrically assisted bicycle seems in some countries to be gradually taking its place as a new intermediate mode of transport between the conventional bicycle and the motorbike or the car and, just like the conventional bicycle, it manages to cope with many problems caused by the automobile. But thanks to a reduction in the effort required, it also remedies certain obstacles to the use of the classic bicycle, such as the relief (variations of the surface of the globe). Does the electrically assisted bicycle, therefore, have a more promising future in Wallonia?

A survey published on bicycle mobility in 2020 in Belgium (GRACQ, n.d.) related that 41 % of Belgians use a bicycle for their journeys at least once a year. Higher usage is observed in

Flanders (55 %) than in Wallonia (20 %) or Brussels (25 %). However, most home-to-work journeys made with a bicycle between 2 and 10 km represent 62 % of the total pathway. Among these cyclist users, 46 % are higher education graduates compared to 30 % of secondary school graduates. On average, 15.6 % of Belgians use a bicycle with electric assistance (VAE) restricted to 25 km/h, at least once a year (GRACQ, n.d.). Higher use in Flanders (22 %) than in Wallonia (7 %) or Brussels (5 %). The majority of home-work journeys with a VAE are between 5 and 20 km (59 %).

3. Method

3.1. Criteria

The university seems a good starting point for promoting the use of bicycles, for simple reasons of proximity, better knowledge of the terrain and easier contacts. In most European countries, universities are among the largest employers in their cities (Balsas, 2003), thus, the University of Liege is the largest employer in the city of Liege. Universities are also one of the largest generators of traffic and thus exert significant impacts on congestion, parking and environmental quality, especially when they are located in urban areas (Rotaris & Danielis, 2015). The travel that a university generates is the biggest impact that it has on the environment (Tolley, 1996). To become more environmentally friendly, many universities have already implemented strategies to reduce reliance on private cars and increase the use of sustainable modes of transport (Rotaris & Danielis, 2015). Universities already seem to be a more willing environment for the use of alternative modes, probably because many students do not own a car due to their limited budget. According to a study in over 100 European cities, a higher proportion of students in a city is indeed associated with higher modal shares for public transport, walking and cycling (Santos et al., 2013). Students are generally more physically fit and often own a bicycle (Balsas, 2003). In addition, students and university staff are generally more environmentally aware and receptive to new ideas. With a proactive educational environment, universities are prime locations to talk about sustainability and thus help reshape society's transport habits (Balsas, 2003). More practically, campuses are often independent areas with their buildings, services, and infrastructure (Balsas, 2003). For all these reasons, universities are very interesting place to implement mobility management and modal shift strategies and to test their performance.

3.2. Location

The University of Liege (ULg) is mainly based in the city of Liege, which is today the major Walloon metropolis and the third-largest urban agglomeration in Belgium. It has over 200,000 inhabitants. The city is located at the crossroads of three natural geographical areas: to the north, the Hesbaye (altitude 160 to 200 m), one of Belgium's main agricultural areas; to the east, the Pays de Herve (200 m to 320 m), a hillier and wooded landscape, a large fruit-growing region; to the south, the Condroz plateaus (200 to 280 m), gateway to the Ardennes where moors and forests dominate and, at 694 m, the highest point in Belgium, the Botrange signal. The University alone is home to almost 30,000 people, including more than 20,000 students (F. Michel, personal communication, 16 April 2016). In Liege city, the university campuses are located in down town (zone of campus 1 of the University of Liege), and 10 km from down town (zone of campus 2), as shown in Fig. 1 below.

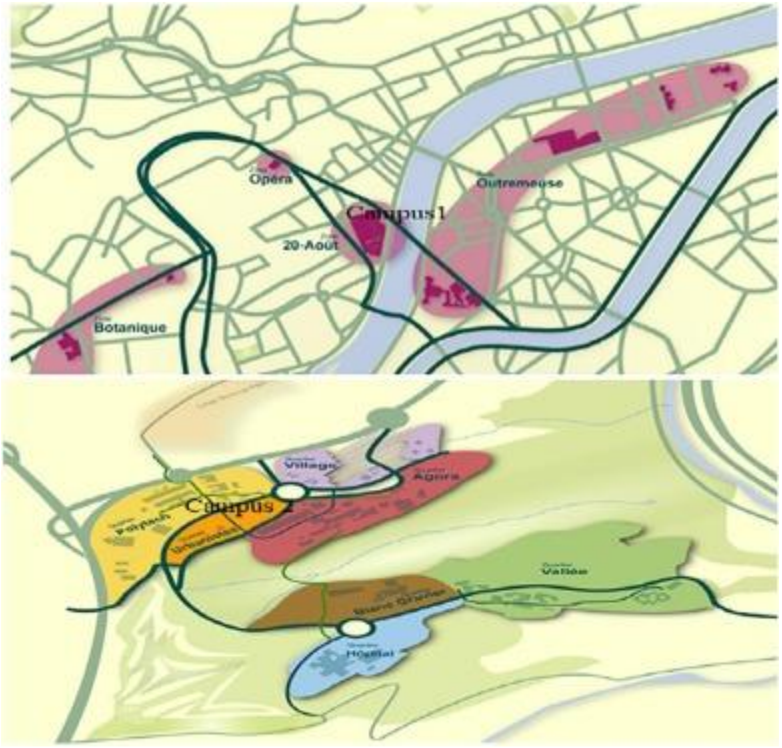

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Fig. 1. Location of the two campuses studied.

3.3. Campaign

3.3.1. Data collection

To gather the views of the university population, a survey of the population concerned seemed to us to be the most relevant research method. The type of survey chosen is quantitative and involves a large number of people. Several surveys have already been carried out to consult the university population on mobility in general. However, none has focused on cycling in particular. A broad survey, both in its questions and in its audience, will therefore provide a comprehensive but detailed view before seeking more specific or qualitative opinions via other research methods. In addition, a survey of a large number of people also makes it possible to differentiate the results according to different profiles. For example, according to status (student, doctoral student or member of staff), according to the area of the campus mainly frequented or according to the modes of transport used, differences which few surveys have looked at to date in the context of the University of Liege (ULg).

A questionnaire on cycling mobility tends to mobilize two main profiles: people with claims or complaints about cycling and people who cycle or support cycling. The questionnaire is indeed an opportunity to either complain about or support mobility in which one believes. In our case, we will indeed show that cyclists are overrepresented. The survey was established in the light of the theoretical part and a more general survey “Mobility of students of the University of Liege” conducted in 2013–2014 by the Cemul-ULg (Bianchet, 2014). The results of this survey helped to orient the questions and to better focus our research.

3.3.2. Questionnaires

A standard voter questionnaire was designed online using Qualtrics software. This questionnaire was designed after a few weeks of intense work between February and March 2016. After the design of the questionnaire, a pre-text was conducted by 15 people, including adults, students and former students, cyclists and non-cyclists, to check whether the questionnaire was comprehensive, clear and whether the answer choices were complete whether the length of the questionnaire was acceptable, etc. As a result of these various interactions, many questions were adapted during the three weeks. With the support of the University's mail service, the questionnaire was sent to more than 28,000 people.

The questions concerning the address and the campus most visited by the respondents were intended to assess the distances involved in commuting to and from the university to study the actual potential of operational bicycles. The following section deals with modes of transport in general. The purpose of these questions is to investigate the transport habits of respondents (and in particular the extent to which cycling is currently used as a mode of transport) and to identify whether responses to the rest of the questionnaire vary according to the current transport habits of individuals.

Two short questions are then asked about satisfaction with modes of transport. The Cemul-ULg survey reported widespread dissatisfaction with the bus, train and car. We hypothesize that active modes of transport are much more satisfying, which we want to verify through these questions.

We then start to look more specifically at cycling. The first set of questions concerns the image of classic and electric bicycles. Through these questions, we will try to identify the extent to which the bicycle is seen as a valid and accessible mode of transport for all, who the users of classic and electric bicycles are and how they are viewed on the road, the extent to which the characteristics of the electric bicycle are known, etc. The next two sections deal with the perception of the determinants.

These questions will aim to evaluate the difference between the way certain determinants are perceived and objective data. It was indeed highlighted in the literature review that the perception of determinants is as important as the determinants seen objectively and that a very simple strategy to promote cycling could be simply to meet the possible misperceptions that users have of these determinants.

A big question then focuses on the determinants of cycling use. Just as the perception of the drivers plays a major role in the choice of a mode of transport, the importance given to these drivers is also essential. To define an effective promotion strategy, it is also necessary to identify which improvements can have the greatest impact on modal shifts. We ask respondents the main reasons why they do not use - or do not use more often - cycling as a mode of transport. As the question is asked in parallel for both conventional and electric bicycles, we will also be able to assess the extent to which the electric bicycle would be a solution to the obstacles encountered.

Finally, we evaluate the proportion of individuals who can store a bicycle at home and identify which strategies for promoting cycling would seem to be the most effective.

3.3.3. Route survey

The methodology used was a map-based identification of the main routes and a quick examination of their elevation profile. In the case of the city centre – Sart-Tilman route, which was studied in more detail, the analysis was then based on a visit to the site by bicycle to observe the realities on the ground (using an observation grid) and an email interview with three cyclists who are used to this route to check the accuracy of our observations and assessments. The different locations and route surveys are shown in Fig. 1.

3.3.4. Cleaning and data pre-processing

All data were processed using Excel, with except for map data which was processed using Google Maps and other applications. Globally, 1496 answers to the questionnaire were saved, representing only 5.2 % of all the people who were contacted for this survey.

Before analysing, all the data were “cleaned”. The average response time for each questionnaire was between 15 and 20 min. However, a few dozen voters completed the entire questionnaire between 5 and 7 min, special attention was paid to the consistency of their answers, but nothing strange was found. During the evaluation, a few other completed questionnaires were however cancelled, either because the voter was not part of the target audience (students having received the survey by mistake), or because of incoherent or systematic answers (for example, one respondent entered “42” or “4242” in all the free fields), etc. In the end, 1206 questionnaires were retained, which represents a response rate of 4.2 %. The optional response “Other” was suggested in the majority of questions. For example, many staff members listed driving children as an “Other” category in the disincentives of cycling. This response was present in the choices but under the heading of “Journey too complex (e.g., changing campuses during the day, stops for shopping or dropping off children, etc.)”. The questionnaire would have been clearer if we had proposed “Having to drive children” directly, not through the journey's complexity. The consistency of the answers to the rest of the questionnaire was also checked for all respondents who gave extreme answers to these questions, and this is partly how complete questionnaires were eventually deleted (Chapman, 2007; Rietveld & Daniel, 2004; Tolley, 1996; Vandenbulcke et al., 2011; Woodcock et al., 2007).
In addition, all respondents indicated the area of the campus that they mainly visited, which made it possible to identify the residence-ULg routes for all respondents who provided their addresses. The following addresses were used to locate the different areas of the campus, thus leading to approximations in some cases. Various data on the residence-ULg trips were collected using Google Maps: distance, ascent and descent, and travel time to and from the residence.

3.4. Sample

Table 1 shows the number of voters, with men slightly under-represented and women over-represented. Therefore, in addition to looking at the sample as a whole, the responses to the questions will be broken down by status and gender.
Table 1. Comparison between a member of ULg and respondents.

Empty Cell		Population of ULg		Sample		Response rate (%)
		People	**Percentage**	**Voters**	**Percentage**	
	Total	29,029	100.0 %	1206	100.0 %	4.2 %
Status	**Student**	20,455	70.0 %	689	57.0 %	3.4 %
	Doctorate	1728	6.0 %	126	10.0 %	7.3 %
	Staff member	6846	24.0 %	391	32.0 %	5.7 %
Sex	**Men**	13,334	46 %	501	42 %	3.8 %
	Women	15,695	54 %	705	58 %	4.5 %

The age of the respondents is relatively variable: 90 % of the students are between 18 and 25, with extremes of 17 and 73, while 90 % of the PhD. students are between 23 and 31 (normal distribution), with extremes of 23 and 50. The age of staff members is much more evenly spread between 23 and 72, with a majority between 29 and 55.

Percentage distribution of the distances travelled by commuters by cycling using classic and electric bikes based on our survey is: 0–5 km (5.5–26.5 %); 5–10 km (5.5–12.5 %); and 10–25 km (0–5.5 %).

3.5. The energy efficiency

The energy efficiency of different modes of conventional and electric bicycles has been calculated using various methods and metrics. For example:

- Energy Consumption: One way to assess energy efficiency is by measuring the energy consumption of a bicycle during operation. This can be done by using power meters or specialized sensors that measure the amount of energy expended to propel the bicycle over a certain distance or time. For electric bicycles, the energy consumption can be measured by monitoring the battery usage.
- Energy Efficiency Ratio: Another method is to calculate the energy efficiency ratio, which is the ratio of the mechanical work output (in the form of propulsion) to the energy input (from the rider or the battery). It is typically expressed as a percentage. A higher energy efficiency ratio indicates a more efficient bicycle.
- Energy Equivalent: The energy equivalent method involves converting the human power input into an equivalent energy value, usually measured in kilocalories or watt-hours. This method allows for comparisons between conventional bicycles (which rely solely on human power) and electric bicycles (which utilize both human and electric power)
- Coasting and Braking Efficiency: Energy efficiency can also be assessed by considering factors such as coasting and braking. A bicycle that maintains momentum well when

coasting downhill or effectively recaptures energy during braking is generally considered more energy-efficient.

- It's worth noting that the energy efficiency of a bicycle can vary based on factors such as rider input, terrain, weather conditions, speed, and the specific design and components of the bicycle. Therefore, different testing protocols and methodologies may be used to obtain accurate and representative energy efficiency measurements.

4. Results and discussion

4.1. Transport modes

Fig. 2 shows the travel time in urban areas as a function of distance and mode of transport. It is based on the assumption of a linear relationship as described by Dekoster and Schollaert (1999). This figure shows that in urban areas, the bicycle is one of the fastest modes of transport for short distances. It avoids traffic jams, and time spent looking for parking or waiting for the bus, the journey time is much more predictable.

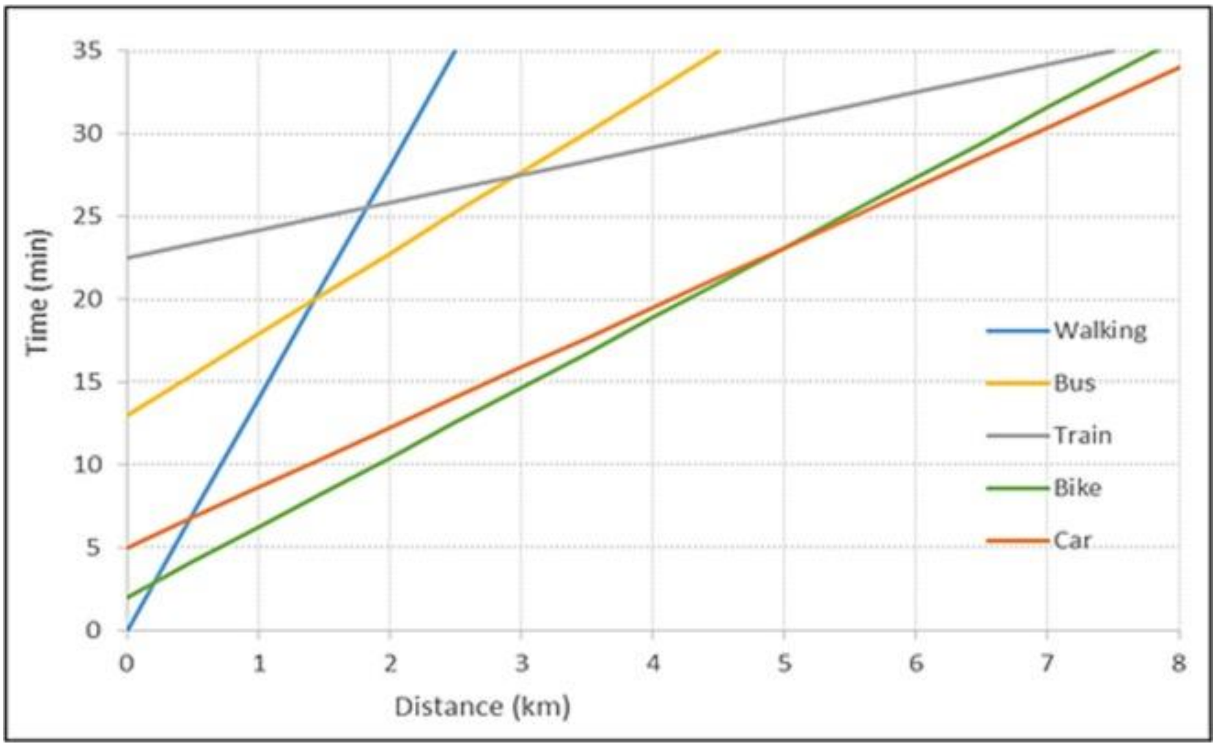

Fig. 2. Travel time in urban areas according to distance and mode of transport.

Fig. 3 shows the modal shares according to distance at the University of Liege.

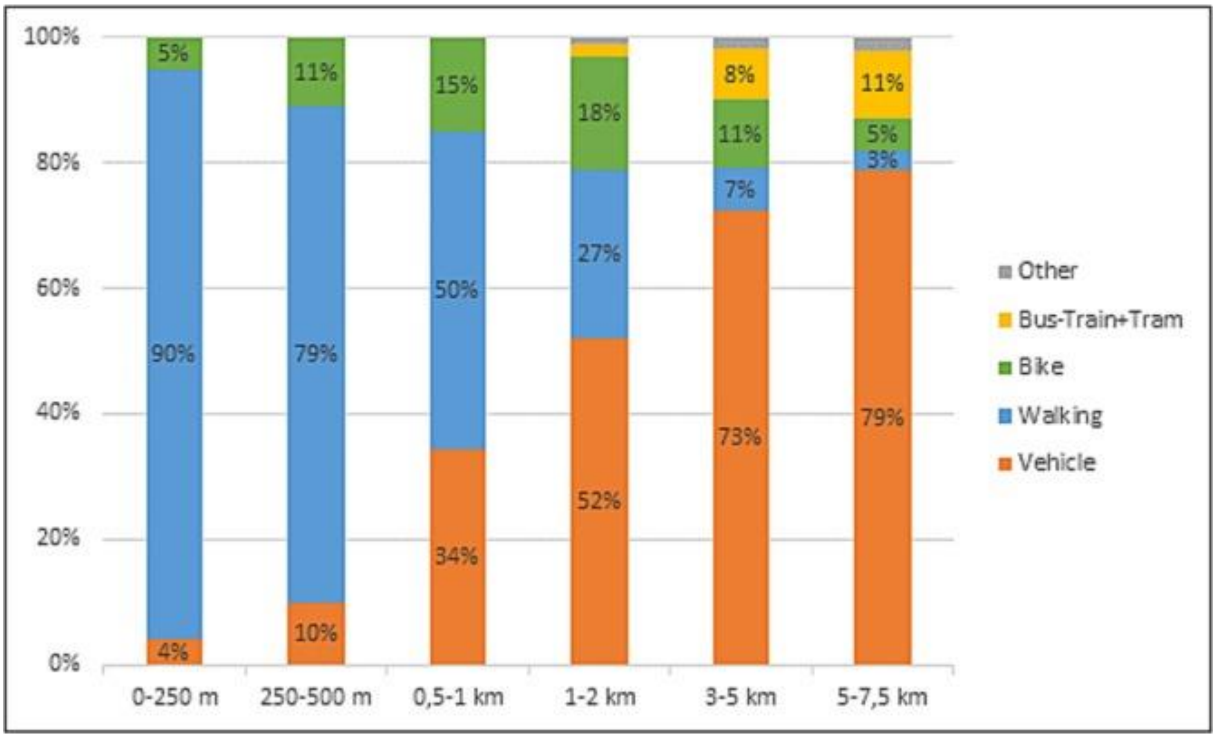

Fig. 3. Modal shares according to distance (Cornelis et al., 2012).

It can be seen that cycling is a very important mode of transport for short distances. However, between 250 m and 500 m, the most of population prefers to walk.

For short trips (less than 7.5 km), there is still a huge potential for a modal shift towards cycling, especially as these trips represent more than half of the trips made on average over a day (Cornelis et al., 2012). These results are consistent with the research by Verhetsel et al. (2007) who found that 60 % of the population were likely to cycle to work.
So far, we have looked at modal shares about the number of trips made. If we now look at how each mode contributes to the distances travelled, the contrast between car and bicycle increases considerably, with the latter being used mainly for short-distance trips. In Belgium, cycling only contributes to 3 % of the total distance travelled, while 76 % of the distance is travelled by car (as driver or passenger). For Wallonia, these figures are 1 % and 80 %, respectively (Cornelis et al., 2012). In the European Union, only 1 % of the total distance is cycled, while 73 % is travelled by car (European Commission, 2012a). To initiate a modal shift towards cycling in Wallonia, it is therefore important to identify the factors that encourage or discourage the population from using the bicycle as a mode of transport. This is what we will focus on in the last part. Such identification can then make it possible to determine appropriate actions and strategies to mitigate the effect of these factors to achieve a modal shift towards cycling (European Commission, 2012a; Vandenbulcke et al., 2011). Fig. 4 shows the modal share of cycling in some countries. It is very interesting to notice that the modal share of cycling was fixed at 28 % Netherlands, 19 % in Denmark, 15 % in Belgium (Flanders region), 12 % in Germany, 8 % in Finland, 2 % in the UK, and only 1 % in the USA. We deduce from these results that bike is the most used in Netherlands and least used in the USA.

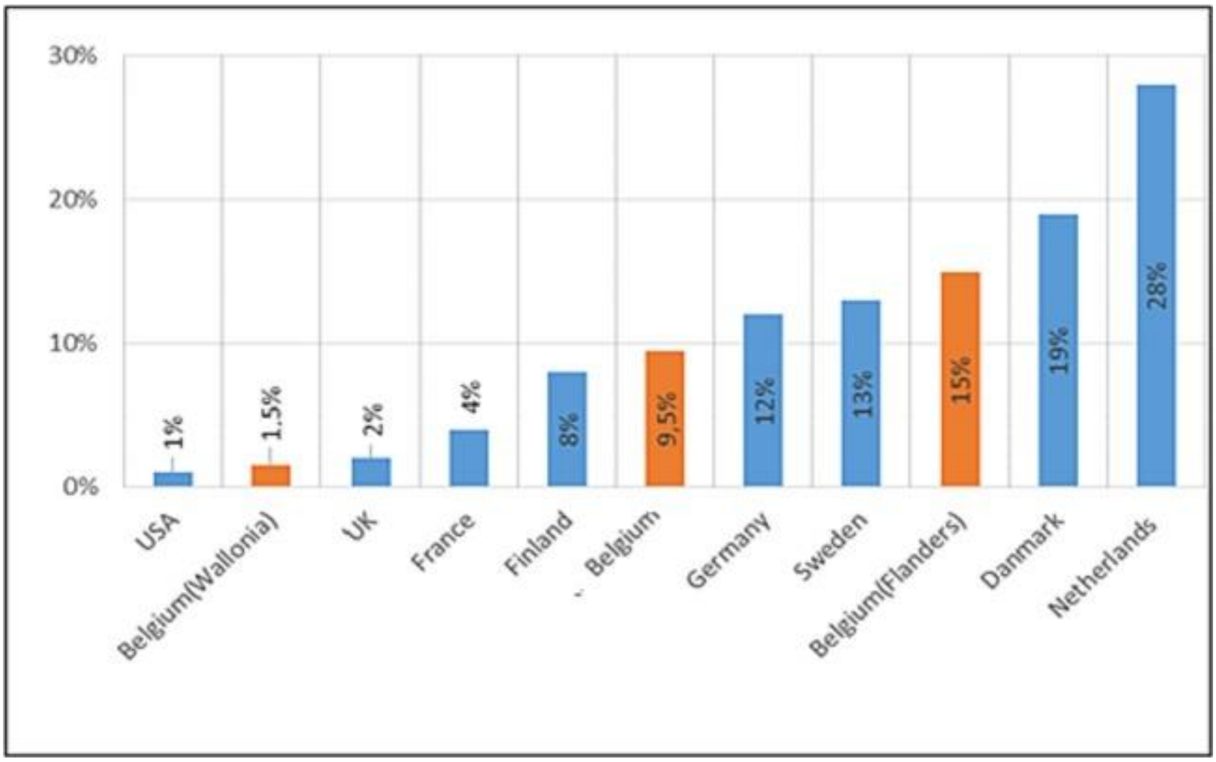

Fig. 4. Comparison of the modal share of cycling in Belgium, Flanders, Wallonia, and other countries in terms of trips made (Pauwels & Andries, 2016).

4.2. Environmental consideration

The progressive electrification of transport modes is a strategy supported by scientists, politicians and industry experts to reduce oil dependency, carbon dioxide emissions and urban air pollution (European Commission, 2012b). However, the addition of a motor and battery makes the question of the sustainability of the electric bicycle legitimate compared to other sustainable modes of transport such as the conventional bicycle or the bus. In this section, we compare the energy consumption and the emission of greenhouse gases and other pollutants of the electric bicycle with other modes of transport.

Of all the electric modes of transport, the electric bicycle is the most energy-efficient. More generally, it has a better energy performance than all other motorized modes of transport, including buses, when considering the whole life cycle (Fig. 5) (Weiss et al., 2015). The amount of energy required and the comparison to other modes of transport depends on the system boundaries. Regardless of the type of analysis, the electric bicycle has the lowest energy consumption compared to all other motorized transport modes. Other electric bicycles perform close to the electric bicycle in a tank-to-wheel analysis, but these benefits decrease in a well-to-wheel analysis (analysis where energy extraction, conversion, and transport are additionally considered) or in a life cycle analysis (analysis where vehicle production, lifetime, etc. are additionally considered) (Weiss et al., 2015). These results are roughly in line with the figures put forward by other authors, such as Cherry et al. (2009) who also carried out a life cycle comparison of various modes of transport, or for example, Ji et al. (2012) and Vandenbulcke et al. (2009) respectively stating that an electric bicycle consumes about 1.8 kWh/100 km, which is one-tenth of the consumption of an electric car, and that traditional motorized two-wheelers consume 2 to 7 times more energy than electric two-wheelers. The car, bus and train consumptions quoted by Weiss et al. (2015) are consistent with the results reported by Figueroa et al. (2014) and Marique and Reiter (2012). Depending on the type of analysis and the assumptions considered, the electric bicycle consumes approximately 12 to 40 times less energy than a traditional car and 5 to 30 times less energy than a bus.

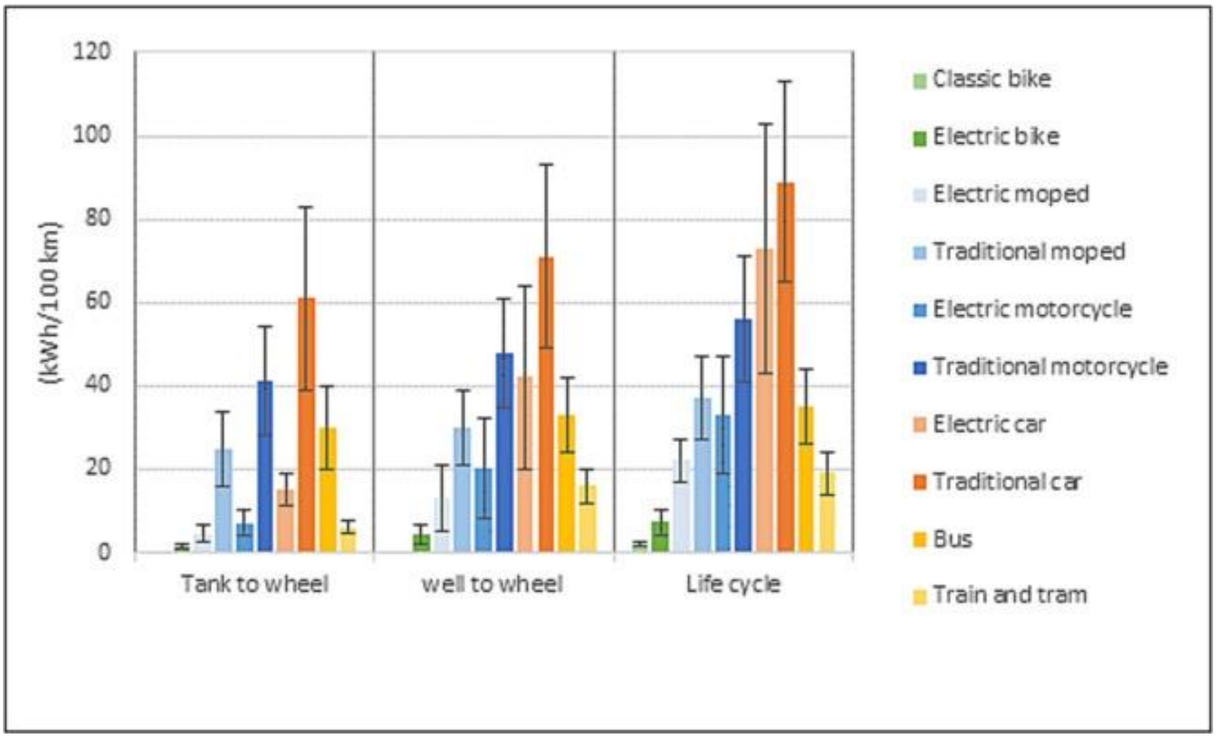

Fig. 5. Comparison of Energy consumption of different modes of transport.

In terms of greenhouse gas emissions (Fig. 6), the electric bicycle also performs better than all other motorized transport modes (Cherry et al., 2009). As with energy consumption, the quantification of these emissions depends on the type of analysis. Greenhouse gas emissions generally follow the same logic as energy consumption (Weiss et al., 2015). However, depending on the source of electricity, the number of emissions can vary significantly. For example, the carbon intensity of electricity generation is 1059 g_{CO2}/kWh in Estonia, where electricity is mainly produced from coal, but 0 g_{CO2}/kWh in Iceland, where electricity is produced from hydropower. In the EU-27, the average carbon intensity was 335 g_{CO2}/kWh in 2010; 314 g_{CO2}/kWh in 2015; 229 g_{CO2}/kWh in 2020; 275 g_{CO2}/kWh in 2021; and is expected to be 110–118 g_{CO2}/kWh in 2030 (https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-12#tab-googlechartid_chart_11, n.d.).

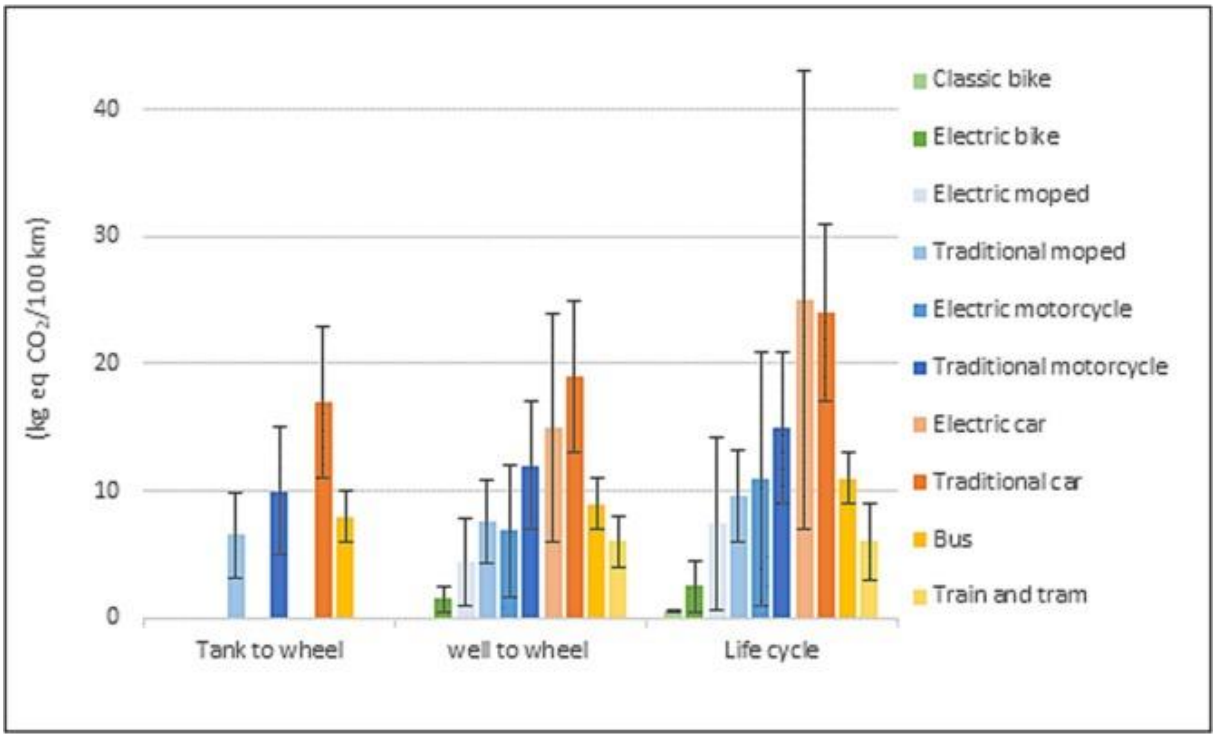

Fig. 6. Comparison of CO_2 emission from different modes of transport (Weiss et al., 2015).

Table 2 shows the amount of CO_2 emissions by energy source. The de-carbonization of electricity generation can significantly reduce the emissions of electric vehicles in life cycle analysis (Weiss et al., 2015). In Belgium, half of the energy mix is nuclear energy, more than a third is fossil energy, and the rest is renewable energy (wind, hydro and photovoltaic). Given Table 2, we can therefore expect a carbon intensity at most equal to the European average.

Table 2. CO_2 emissions by energy source (Roetynck, 2010).

Source of energy	**Emission of CO_2 (g/kWh)**
Wind energy	9–25
Hydropower	8–33
Photovoltaic	50–60
Nuclear	3.5–100
Biomass	0–540
Gas	350–450
Charcoal	850–1000

For emissions of other pollutants, the results shown in Fig. 7 are from studies in China (Cherry et al., 2009). Electric bicycles and other types of electric two-wheelers perform significantly better than conventional motorbikes and cars in terms of carbon monoxide, hydrocarbons, nitrogen oxide and fine particles. Compared to buses, however, only carbon monoxide and hydrocarbon emissions are lower for electric two-wheelers. The performance of electric two-wheelers is worse for sulphur dioxide emissions. This is because, in China, 75 % of electricity is generated by burning coal, one of the main sources of sulphur dioxide. More positive results can therefore be expected in Europe. The most critical environmental impact of electric two-wheelers is lead emissions from the production, recycling and disposal of lead-acid batteries, which are the most widely used in China. However, in Europe, lead pollution is not a problem simply because lead-acid batteries are no longer used and electric two-wheelers are equipped with Li-ion or Ni-Mh batteries (Cherry et al., 2009; Weinert & VanGelder, 2009).

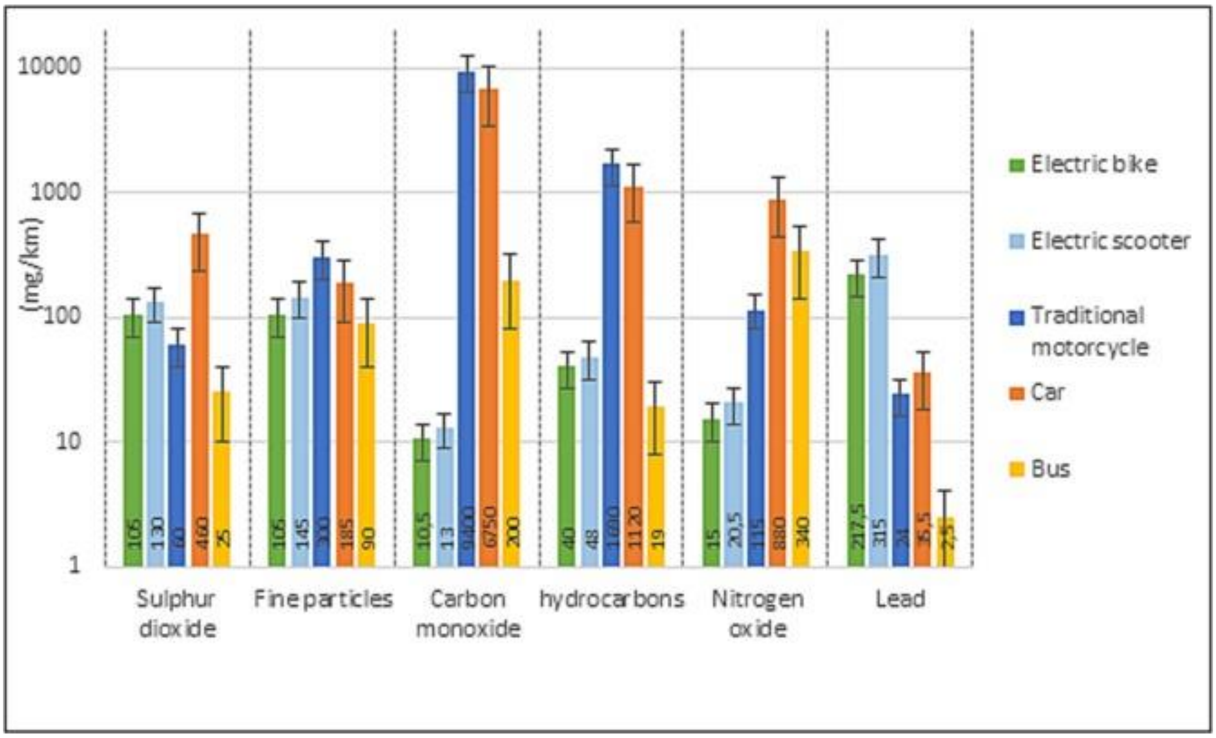

Fig. 7. Comparison of pollutant emissions of different modes of transport (Cherry et al., 2009).

It should be noted that the emissions of electric two-wheelers can be improved by choosing natural gas or renewable energies as the source of electricity instead of coal, for example, or by improving the treatment of smoke coming out of the power stations (Cherry et al., 2009; Ji et al., 2012). Finally, it is important to note that emissions of greenhouse gases and other pollutants occur at power plants. Therefore, environmental impacts are shifted from the vehicles themselves, which are numerous and difficult to control, to more concentrated points, mainly located outside urban areas. This reduces the exposure of the population to emissions and therefore reduces the negative impacts on the health of transport systems (Ji et al., 2012).
Although lower than those generated by any other mode of motorized transport, the environmental impacts of the electric bicycle are not non-existent. Compared to traditional modes, the environmental impacts are transferred from the use of the vehicle to its production, end-of-life treatment and electricity generation (Weiss et al., 2015). The production and recycling of batteries is an environmental challenge that electric bicycles face (van der Kuijp et al., 2013). Overall, the production phase of vehicles accounts for more than half of the life cycle energy consumption. The production of electricity for its use, although decentralized, is not

without environmental impacts either, and conversion losses can reach up to 70 % if the electricity is derived from fossil fuels (Cherry et al., 2009; Weiss et al., 2015). In conclusion, it can be said that the e-bike has a better environmental performance than all other motorized modes of transport on almost all indicators and compared to conventional cycling and public transport, which are sustainable modes of transport, the e-bike scores well (Weiss et al., 2015), but there is still room for various improvements.

4.3. Residence-ULG pathway

In Fig. 8, we see the distances between residences and university campuses, evaluated with Google Maps, and divided into 5 classes. The different classes were divided based on numerous research works (Héran, 2012; Vandenbulcke et al., 2011; Wolf & Seebauer, 2014), some of which proposed that below 1 km, most of the population would like to walk, that the limited distance between residence and workplace with a conventional bicycle is estimated to be between 7 and 10 km, and that in general, the trips of the population with an electric bicycle were estimated to be 1.5 times further than the trips of the population with a conventional bicycle. On this basis, it was adopted the following classes:

- Around 1 km: Greater preference for walking as a mode of travel,
- 1 to 4 km: Greater preference for cycling as a mode of travel,
- 4 to 8 km: Greater preference for cycling,
- 8 to 12 km: Greater preference for using an electric bicycle,
- More than 12 km: greater preference for other modes of transport (bus, coach, tram, metro).

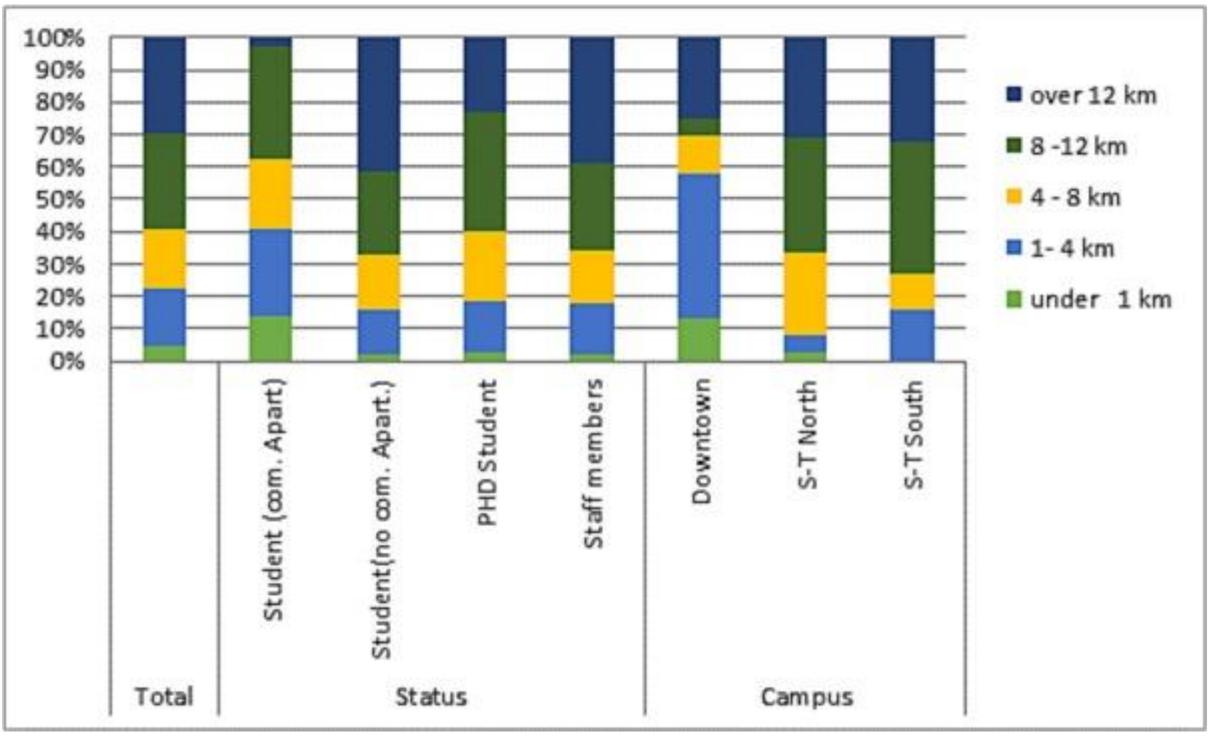

Fig. 8. Distance travelled (in km) from residence to the school for the voters of our study and their frequency function of status.

In total, 65 % of voters live between 1 and 12 km from the campus they study or work most often, and the remaining 36 % live between 1 and 8 km away. From this result, it can be concluded that a large number of the population is likely to use the bicycle regularly as their main mode of transport. These different percentages increase to over 80 % if we consider only students living in halls of residence or student houses, while they decrease slightly for students living with families and also university employees. The number of voters living between 1 and 12 km from the campus they are studying is almost similar for each campus; however, most people going to the city centre live within 4 km, while most people going to the Sart-Tilman campus live more than 8 km away. This finding shows greater potential for using the less conventional bicycle to go to the city centre.

4.4. Modes and transport

To assess mobility patterns, the following question was asked to the voters:

How often each mode of transport is used in daily life (Fig. 9)? In addition to studying modal shares, this question had several purposes. Firstly, it allows a comparison with other surveys to study whether there has been an evolution of modal choices over time and to identify a possible bias if some results seem inconsistent. Taking all types of transport together, cycling has a modal share of 6.2 % of the sample. Concerning the total population of the ULg, this would represent 1800 bicycles (including almost 350 electric bicycles).

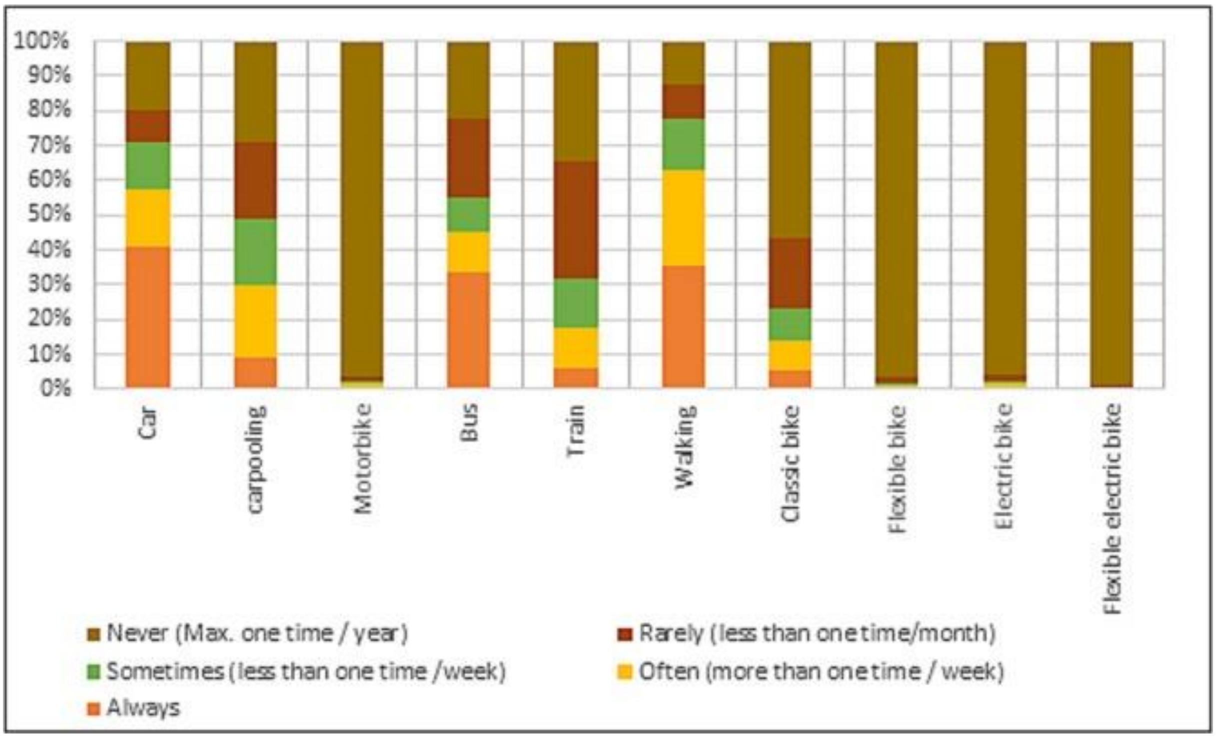

Fig. 9. Frequency of use of different modes of transport.

Firstly, regarding transport mode by “Bus”, the 34% voted “always”, 12 % voted “often”, 10 % for “sometimes”, 22 % voted “Rarely”, and 22 % voted “Never”. Secondly, for walking, 35 % voted “always”, 27 % voted “Often”, 15 % “sometimes”, 10 % voted “rarely”, and 12 % voted “never”; thirdly, for moving by classic bike, only 6 % voted “always”, the 9 % voted “often, and sometimes”, the 20 % voted “rarely”, and 56 % for “never”.

Finally, for the question related to moving by electric bike, only 1 % of participants voted “always”, “often”, and, “rarely”. Nobody has selected “sometimes”. Up to 96 % of voters have selected “never”.

Fig. 10 shows the different modes of travel according to the ICEDD and Cemul-ULg surveys compared to those found in this study. We notice a significant decrease in the use of the car in favour of public transport (train, bus, carpooling, etc.) and also soft mobility, both among students and employees of the university. In comparison with the Cemul-ULg survey, it is interesting to note a significant increase in the use of private cars among students, but also a slight increase in the number of people who prefer to walk.

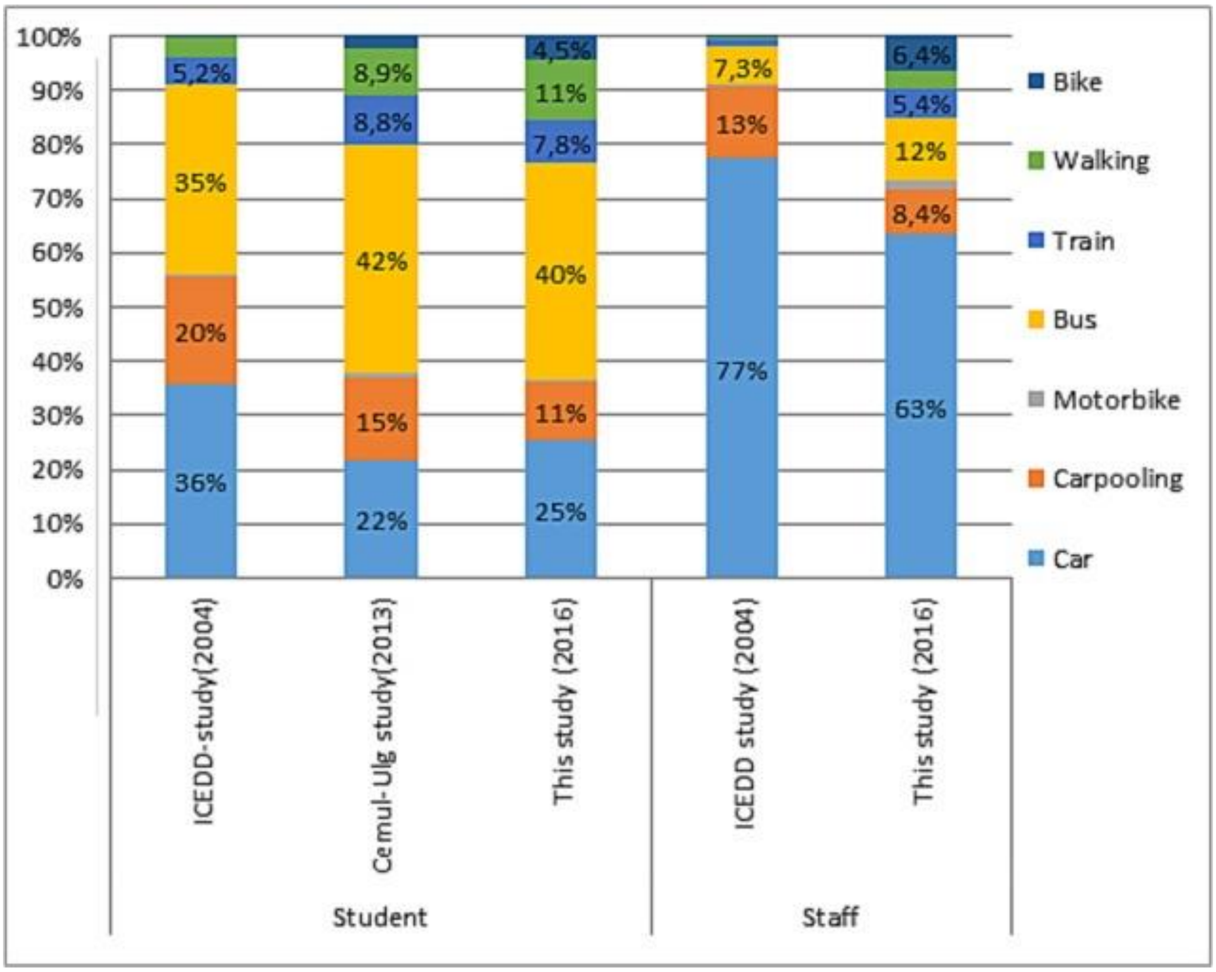

Fig. 10. Comparison of results obtained in several surveys.

Cycling is used almost twice as much by men as by women. It is also used almost twice as much in the city centre as in rural areas (SartTilman). Finally, doctoral students are the most avid users, almost three times more than other categories, while students are proportionally the least likely to use a bicycle. The majority of users are conventional bicycles, although electric bicycles account for almost one-fifth of the modal share. Folding bicycles, on the other hand, are used very little. People living less than 4 km from ULg use bicycles the most. It is used three times less by people living between 4 and 12 km from ULg, and its modal share becomes insignificant beyond 12 km. Between 1 and 12 km, the modal share of electric and folding bicycles increases slightly, while the modal share of the classic bicycle drops significantly at 4 km. Between 4 and 8 km and 8 and 12 km, however, there are no major differences.

4.5. Disincentives to cycling

In parallel, for the conventional and electric bicycle, a list of obstacles to the use of the bicycle was proposed to the respondents (the question was only asked of those who do not use the bicycle as their main means of transport, i.e., 1131 people or 94 % of the sample). Fig. 11 shows the obstacles cited by all respondents for conventional and electric bicycles, ranked in order of importance for the conventional bicycle.

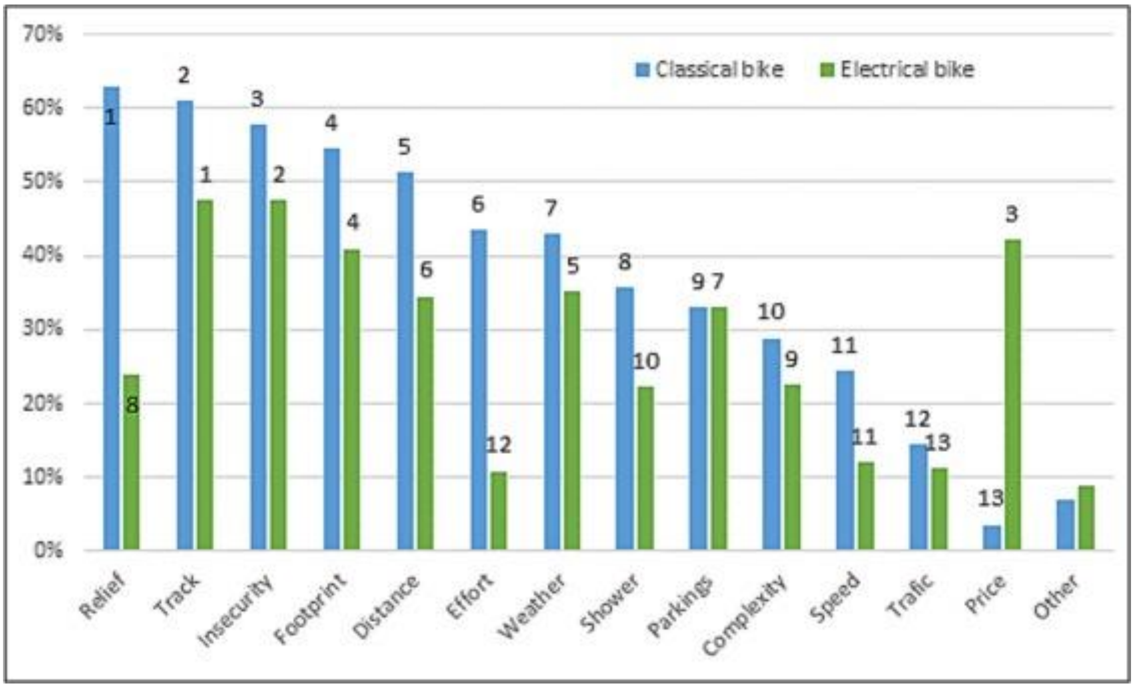

Fig. 11. Barriers to using the bicycle as a mode of transport and order of importance.

The lack of cycle paths and road safety are major obstacles to the use of bicycles, both conventional and electric, as a mode of transport. The terrain is the most important obstacle to the use of a conventional bicycle, but its importance in the eyes of respondents drops considerably for electric bicycles. It is cited by 2.6 times fewer people and drops from 1st to 8th place out of 13 in the order of most important “brakes”. More generally, the importance given to many of the “brakes” is lower when considering the e-bike instead of the conventional bike. Only a few “brakes” are more important for the electric bicycle than for the conventional bicycle: the lack of parking is very slightly more important for the electric bicycle, and the price of the bicycle, which is of minimal importance for the conventional bicycle, comes in 3rd position for the electric bicycle and is cited by 12 times more respondents than for the conventional bicycle. The answers given in the “Other” category were very diverse. The most frequently cited reasons were that the journey was too short and could be made just as quickly on foot, the extra time needed to make the journey and take a shower, and the need to have suitable equipment (implying that women could not wear skirts or heels). Several respondents also mentioned the cold, the lack of urban lighting, the need or obligation to use the car for professional reasons, not knowing how to ride a bicycle, or not owning one. Finally, some respondents mentioned the lack of intermodality, lack of motivation, health problems preventing them from cycling, problems related to their schedules, fear of theft, poor quality of cycle paths, or the fact that they do not like cycling. More specifically for e-bikes, respondents mainly cited a lack of interest in e-bikes or a preference for conventional bicycles, but some also expressed concerns about the weight of the bike and the battery charge or a lack of knowledge about e-bikes.

Despite this, it is interesting to note that cycling offers an answer to many problems. First of all, it is a “green” mode of transport, which - apart from its production - uses no energy, produces no emissions and causes no air pollution. The bicycle is silent and therefore does not emit noise pollution. It is also affordable for most households and accessible to most people, especially young people, who cannot drive a car. Finally, compared to the car, cycling requires little space, either in terms of parking or road infrastructure, and the associated costs are therefore significantly reduced (Dill & Rose, 2012; Johnson & Rose, 2013; MacArthur et al., 2014; Popovich et al., 2014; Timmermans et al., 2003). Fig. 12 shows the factors cited as limitations with respect to electric bicycles depending on the type of profile of the respondent.

in %		Bike path	Insecurity	Price	Congestion	Weather	Distance	Parking	Relief	Complexity	Bath	Speed	Effort	Traffic	Other
Total		47	47	42	41	35	34	33	24	23	22	12	11	11	9
Sex	Male	47	44	44	35	32	30	33	21	18	25	12	9	11	11
	Female	48	50	41	45	37	37	33	25	26	20	12	12	11	8
Status	Student	47	46	48	46	39	35	36	26	18	21	15	12	10	8
	PHD student	50	52	50	39	33	27	35	19	16	29	7	7	11	12
	staff	47	49	30	33	29	36	28	22	33	22	9	11	14	10
Campus	Downtown	41	44	46	38	32	28	32	14	19	16	6	7	8	10
	ST North	50	49	40	41	35	38	30	27	23	25	15	13	12	8
	ST South	49	48	42	43	38	33	40	25	24	22	11	11	13	10
Mode of transport	Car	46	46	32	40	35	41	30	25	32	23	13	10	12	9
	Bus	52	52	52	42	38	27	35	26	15	23	12	13	11	6

Fig. 12. Limitations with respect to the use of electric cycling as a mode of transport according to the type of respondent profile.

The lack of safe cycle lanes is a major obstacle with respect to the use of electric bicycles as means of transport.

4.6. Analysis and comparison of results

In this part, it is analysed and compared the main results presented in the different previous parts. As a reminder, in total, 70 % of respondents live less than 12 km from the campus they most often visit, including 29 % between 8 and 12 km, 18 % between 4 and 8 km, 18 % between 1 and 4 km, and 5 % within 1 km. When we compare the modal share of the bicycle according to the residence-ULg distance, we see that the limit beyond which the conventional bicycle is much less used seems to be around 4 km, while the bicycle remains as much used between 4 and 8 km than between 8 and 12 km. The 4 km limit corresponds to the radius beyond which the topography becomes restrictive, and it is also from this distance that the modal share of the electric bike becomes much greater. Below 1 km, the modal share of cycling is less than between 1 and 4 km but remains higher than the modal share it represents for distances greater than 4 km.

By considering both the distance and the terrain, we, therefore, conclude that a large number of people could get to the ULg by bike. The potential for e-bike use is approximately twice that of conventional bicycles, but a significant number of people are still likely to use conventional bicycles as a mode of transport, especially people travelling to the city centre. Active modes of transport, and especially cycling, are seen by respondents as much more satisfying than motorized modes of transport, including the car. Of course, various factors can explain this dissatisfaction. In particular, we can imagine that many cyclists are by choice, and it is, therefore, normal that they are satisfied with it, whereas bus users, for example, are perhaps much more often by obligation. Dissatisfaction linked to the car, bus, or train is not necessarily linked to the mode of transport itself, but to other factors such as the lack of parking lots, unsuitable or non-respected timetables, lack of comfort, etc.

However, among the motorized modes of transport, the car remains the most satisfying mode of transport. The Cemul-ULg survey studies the evolution of students' mode of transport during their studies and indeed shows a significant modal shift towards the car: 24 % of respondents say they have changed the mode of transport during their studies. Of these, 69 % have opted for the car (58 % as a driver and 11 % as a passenger), and this modal shift mainly takes place from the bus, which is by far the most unsatisfactory mode of transport. Current mobility conditions, therefore, make the car the most attractive mode of transport, a trend that absolutely must be reversed if we wish to reduce the modal share of the car, and that it would be possible to change in view of the much greater satisfaction provided by active modes of transport.

We were able to observe that the lack of cycle paths and road insecurity were the most important obstacles to the use of the bicycle as a mode of transport, whether conventional or electric. In general, the importance given to many determinants is less if we consider the electric bicycle instead of the conventional bicycle. In view of the literature review, we could expect such results regarding the terrain, clutter, effort, weather, showers, complexity, or even speed, because reducing the effort required on an electric bike helps mitigate these brakes. On the other hand, these results are a little more surprising with regard to cycle paths, insecurity, or traffic, since the review of the literature does not reveal any improvement in these determinants by the electric bicycle or even greater risk in this respect insecurity. Our first hypothesis in relation to this is that for some people, other determinants such as the price of the electric bicycle become more important in relation to the presence of cycle paths or safety. A second hypothesis could be that after completing the question for the classic bike, some respondents were tired of completing the question for the electric bike with the same seriousness. In accordance with the review of the literature, other determinants, such as parking and the purchase price, are on the other hand more important for the electric bicycle than for the conventional bicycle. Finally, the majority of obstacles are perceived as more important by women than by men, which is also consistent with the review of the literature. The problem of relief, the most important obstacle to the use of the classic bicycle, seems to a large extent to be overcome by the use of the electric bicycle. On the other hand, its price must be more affordable to encourage more people to use the electric bike.

5. Limitations, risks, and disadvantages of electric bikes

5.1. Visibility

According to various surveys, e-bikes are not seen as a suitable mode of transport for everyone. A German survey shows, for example, that the e-bike is seen as a more suitable mode of transport or leisure for the elderly or people in poor physical condition than for the rest of the population (Hendriksen et al., 2008). In Belgium, the perception of potential e-bike users is somewhat different, and according to a Flemish survey, commuters are seen as the most typical users, but they are again directly followed by the elderly and less athletic people who want to exercise (Timmermans et al., 2003). In addition, many people seem to consider the e-bike only as a leisure activity and not as a mode of transport, while others consider it as a "cheat" compared to the conventional bicycle (Popovich et al., 2014). All this may lead to various stereotypes preventing the e-bike from spreading more widely as a mode of transport. However, the image of the e-bike is far from being only negative, and with appropriate promotion systems, the image of the e-bike could, on the contrary, play in its favour. For example, one survey shows that many people who have bought an electric bicycle for leisure and sport end up using it as a mode of transport as well after finding it convenient and pleasant to ride (Popovich et al., 2014). Other surveys show that without a particular attraction to cycling at the outset, many people who are concerned about reducing their ecological footprint eventually choose the electric bicycle as a mode of transport (Johnson & Rose, 2013; MacArthur et al., 2014; Popovich et al., 2014). Finally, Popovich et al. (2014) further suggest that the social network and the influence of our acquaintances play an extremely important role, with most of the participants in their survey claiming to have bought an electric bicycle on the advice of a relative.

5.2. Cost

Because of the battery and motor, the purchase price of an electric bicycle is significantly higher than for a conventional bicycle of similar quality, and this seems to be one of the main barriers to its adoption (Dill & Rose, 2012; Popovich et al., 2014; Rose, 2012). The price of an electric bicycle varies significantly from €100 in China for a bicycle with a lead-acid battery to 5600 € in Europe for a lithium battery (Weiss et al., 2015). According to a survey in Ghent, however, the price of an electric bicycle is still affordable for the Belgian middle class (Cornelis et al., 2012). While electric bicycles may be expensive compared to conventional bicycles, they are significantly cheaper than cars and motorbikes. In some cases, public transport, even including the cost of replacing the battery (Popovich et al., 2014; Weinert & VanGelder, 2009). But the high cost of the electric bicycle compared to the conventional bicycle also exacerbates the fear of theft (Popovich et al., 2014). The presence of secure bicycle parking becomes an even more important determinant than the conventional bicycle.

5.3. Weight

For example, the weight of bikes sold today at Decathlon (n.d.-b) is between 14 and 19 kg for a conventional bike and between 23 and 28 kg for an electric bike (Decathlon, n.d.-a, Decathlon, n.d.-b). In a study in California, almost all participants (especially women and older people) reported this as a problem because the bike becomes difficult to manoeuvre when the motor is not running and pointed out that it is difficult to carry it for storage (Popovich et al., 2014). Starting, stopping, and stabilizing the bike also require more difficult steering than a conventional bike (Kooijman et al., 2011).

5.4. Battery lifetime

Although the electric bicycle can be used in the same way as a conventional bicycle when the motor is not working, the weight of the bicycle makes it more difficult to manoeuvre and the fact that it is used by people who are sometimes in less good condition. Physics makes battery life a concern (Popovich et al., 2014). However, this fear is somewhat unfounded since the current batteries allow a largely sufficient autonomy for daily journeys. In addition, most electric bikes indicate the level of battery charge, making recharging predictable, and some bikes are even equipped with a spare battery (Roetynck, 2010).

5.5. Security

With increasing use, e-bikes are changing traffic dynamics and giving rise to new situations and interactions between road users. Several studies are attempting to investigate the safety, but little is known at present, particularly in Europe (Dozza et al., 2015; Langford et al., 2015). The studies also report mixed results, with little consensus on whether e-bikes are inherently more dangerous than other modes of transport (Cherry et al., 2016). However, it seems that safety is the most important issue in relation to the growth of the e-bike market, to the extent that they have been banned in some cities in China (Cherry et al., 2016; Weinert & VanGelder, 2009). Chinese traffic police argued that electric two-wheelers have a rough ride disturb motorists, and are a threat to conventional cyclists when riding on bike paths, further causing a bad perception of electric bikes by all the other users (Weinert & VanGelder, 2009). Also in Paris, electric two-wheelers are associated with both a higher number of accidents and more serious accidents (Weiss et al., 2015). In the Netherlands, Van Boggelen et al. (2013) noted a 30 % greater risk of having an accident among electric bike users than among conventional bike users. In Switzerland, unlike the latter authors, Weber et al. (2014) reported that users of an electric bicycle are not more often involved in an accident than conventional cyclist, but that the proportion of injuries bass is slightly higher.

6. Advantages of electric bicycles compared to conventional bicycles

Among the reasons listed for using the bicycle as a mode of transport, many are those that obviously remain valid for the electric bicycle, for example, regarding the space and the investments required for the infrastructures, noise pollution or visual, its impact on congestion, etc. In particular, we have just shown that despite the addition of the motor and the battery, the electric bicycle remains a sustainable mode of transport that consumes very little energy and produces very few emissions. However, electrical technology may still question the retention of health-related benefits. Despite the reduction in the effort to be provided thanks to electric assistance, the health benefits also remain present in the use of the electric bicycle (e.g. Gojanovic et al., 2011; Louis et al., 2012). Indeed, a study showed that the effort required by the electric bicycle was sufficient to reach the standards of physical activity prescribed by the American College of Sports Medicine for adults (Simons et al., 2009). Public, it is by moving from inactivity to moderate physical activity that the greatest improvements can take place (Louis et al., 2012; Pate et al., 1995). Consequently, replacing the car with the electric bicycle would have a very beneficial impact in terms of public health (Popovich et al., 2014). Some authors announce that health-related benefits can be observed even among users exchanging a conventional bicycle for an electric bicycle in more specific contexts because muscle fatigue and physiological stress are less (Theurel et al., 2012).

The reduction in the effort to be provided compared to the conventional bicycle is the main characteristic of the electric bicycle, and this makes it possible to improve many determinants of the use of the bicycle. First of all, with regard to the attitude towards sport, if it is a pleasure of riding a bicycle and doing a sport that motivates classic cyclists, the electric bicycle is on the contrary attractive because it allows not make too much of an effort and therefore arrive at your destination less tired and less sweaty (KairosWirkungsforschung und Entwicklung, 2010). Thanks to electric assistance, the electric bike is more easily used than the classic bike by people with physical limitations, and for people who do not already have sufficient physical condition, the electric bike can also serve as a transition to the classic bicycle (Popovich et al., 2014). In particular, by limiting the effort required to pedal and alleviating the associated pain in the muscles, knees, or back, the electric bicycle can be more easily used by the elderly (Popovich et al., 2014), thus reducing the impact of age. It is also a mode of transport appreciated by women as much as by men (Astegiano et al., 2015), which is not the case with the classic bicycle, and gender thus becomes a less important determinant. Electric assistance makes it possible to go faster with less effort, which therefore makes it possible to reduce travel time and/or increase the distance travelled (Langford et al., 2015; Popovich et al., 2014), two major determinants. It has been shown that journeys by electric bicycle are on average longer than by conventional bicycle, for less fatigue and perspiration (Ahrens et al., 2013; Cherry et al., 2016; Langford et al., 2015). In the Netherlands, for example, the average distance of a trip by electric bike (9.8 km) is 1.5 times longer than by conventional bike (6.5 km) (Weiss et al., 2015); the results are similar in China with journeys 9 to 32 % longer (Langford et al., 2015; Weiss et al., 2015). According to Roetynck (2010), the maximum distance for home-to-work travel is 7 km on a conventional bicycle but goes up to 15 km on an electric bicycle. In terms of travel time, saving time is an important determinant of the use of the electric bicycle compared to the conventional bicycle, but also compared to other modes of transport, since in many cases and more important than the conventional bicycle, the electric bicycle is faster than public transport, especially in urban areas or for short journeys (Langford et al., 2015; Roetynck, 2010).

7. Strategies and recommendations

Many actions, more or less easy to implement, make it possible to act on the determinants listed above and encourage cycling. We cite a few examples below.

- The construction of quality cycle paths (or the reallocation of part of the road space) stimulates the use of bicycles, in particular by making it possible to improve both objective safety (reduction in the number of accidents) and subjective (reduction of fears and fears felt by the population) as well as the comfort of cyclists.

- A small separation distance between the cycle path and the road can already help reduce the exposure of cyclists to vehicle pollution, particularly fine particle emissions. It is sometimes important to provide a separation between the cycle path and pedestrians in order to avoid a significant reduction in speed for cyclists (Johnson & Rose, 2013).

- The development of various facilities (bicycle parking lots, showers, changing rooms, lockers, etc.) encourages the use of bicycles. More specifically, the development of bicycle parking lots at train stations and bus stops or the possibility of taking one's bicycle on public transport allows it to be integrated into a multimodal chain, thus making it possible to travel longer journeys and therefore affecting much more potential cyclists. Using an e-bike makes the problem of terrain significantly less important, but when building a bike path, choosing a path along which the hills would be longer but gentler (highest average slope low as possible) can also help.

- Companies can make cycling financially attractive by offering, for example, a per-kilometre allowance, assistance with the purchase of a bicycle or a company bicycle.

- Promotional campaigns (e.g., highlighting health, environmental, economic or mobility benefits) can help reduce socio-economic problems, while education programs can improve safety by teaching cyclists to ride in traffic and other road users to share the road.

- Spatial planning also has a very important role to play. Preventing urban sprawl and promoting density and a mix of functions reduces distances and therefore encourages the use of bicycles.

- Carefully choosing the location of places of work and education, as well as increasing the supply of housing around them, is extremely important.

- Regulations to reduce car traffic (such as strict paid parking policies, reduction of road space allocated to the car, speed limits, introduction of congestion charges or additional taxes, increase in fuel prices etc.) discourage the use of private cars.

8. Conclusion

Among the many possible alternatives, this work is interested in the possibility of a modal shift towards bicycles, with as a case study the journeys between residence and place of classes/work generated by the University of Liège. The results of this study prove that the bicycle is one of the modes of travel most appreciated by users compared to motorized modes of transport. Despite this, many obstacles prevent a more favourable modal shift. The lack of cycle paths and road insecurity are considerable obstacles to the use of bicycles, both conventional and electric. The relief, recognized as the most important obstacle to the use of the classic bicycle, can be overcome by the electric bicycle, but the price of the latter currently restricts its adoption. The study of residence-ULg routes has shown that, despite the distance and the difference in altitude, a large number of people are likely to travel by conventional bicycle, but the potential of the electric bicycle is twice as great. Cycling is used almost twice as much by men as by women. It is also used almost twice as much in the city centre as in rural areas. Several strategies have been proposed to promote the use of bicycles. It is important to install secure cycle paths which will allow the university population to have a continuous and secure route between their residence and the ULg. The presence of secure bicycle parking at home and the ULg must also be guaranteed. Install showers in the buildings, make the electric bike price more accessible (via subsidies or thanks to rental systems), extend the bicycle allowance to all staff and doctoral students, or even organize awareness campaigns or various communications. Finally, it seems important to us to underline the limits of this work and some points that we have not or little addressed but which would deserve to be developed in future work. This work targeted the bicycle as the primary and only mode of transportation. However, combining the bicycle with the train or the bus makes it possible to cover longer distances and therefore to reach more potential users. To extend this study, it would be interesting to study the bicycle as a mode of transport in a multimodal chain, as well as ways to promote intermodality. The case study chosen for this work was limited to the residence-ULg transfer. Other routes (e.g., residence shopping) must also be studied. One of the advantages of this study is that the method applied in this research can be extended to other urban regions of the world. The reproduction of this method in other European cities should normally lead to the same conclusions.

List of the questionnaire

https://docs.google.com/document/d/1SxY7KvNGkiKVbhJMkjtswB_yIdHfwO8L/edit?usp=sharing&ouid=110061605177641892037&rtpof=true&sd=true.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that support this research and other findings of this paper are available from this link: https://docs.google.com/spreadsheets/d/1bISsw5BhrCu6lpNn_ZOzI6HxUaHXvnKX/edit?usp=sharing&ouid=110061605177641892037&rtpof=true&sd=true.

References

G. Ahrens, U. Becker, T. Böhmer, F. Richter, R. Wittwer. Potential of cycling to reduce emissions in road transport. *Report UBA-FB 001731* on behalf of the German Federal Environment Agency (2013).

P. Astegiano, C.M.J. Tampère, C. Beckx. A preliminary analysis over the factors related with the possession of an electric bike. *Transportation Research Procedia*, 10 (2015), pp. 393-402, 10.1016/j.trpro.2015.09.089

J. Bachand-Marleau, B.H.Y. Lee, A.M. El-Geneidy. Better understanding of factors influencing likelihood of using shared bicycle systems and frequency of use. *Transportation Research Record: Journal of the Transportation Research Board*, 2314 (2012)

C.J.L. Balsas. Sustainable transportation planning on college campuses. *Transport Policy*, 10 (1) (2003), pp. 35-49, 10.1016/S0967-070X(02)00028-8

B. Bianchet. Enquête Cemul-ULg: Mobilité des étudiants de l'Université de Liège, Principaux résultats. Consulté le 29 février 2016 à l'adresse : https://www.ulg.ac.be/cms/c_5813799/fr/enquete-cemul-etudiants-ulg-synthese-resultats (2014)

L. Chapman. Transport and climate change: A review. *Journal of Transport Geography*, 15 (2007), pp. 354-367

C.R. Cherry, J.X. Weinert, Y. Xinmiao. Comparative environmental impacts of electric bikes in China. **Transportation Research Part D: Transport and Environment,** 14 (5) (2009), pp. 281-290, 10.1016/j.trd.2008.11.003

C.R. Cherry, H. Yang, L.R. Jones, M. He. Dynamics of electric bike ownership and use in Kunming, China. *Transport Policy*, 45 (2016), pp. 127-135, 10.1016/j.tranpol.2015.09.007

CNLIC. Chinese light industry yearbook (2010−2013). China National Light Industry Association, Beijing, China (2013)

T. Cole-Hunter, D. Donaire-Gonzalez, A. Curto, A. Ambros, A. Valentin, J. Garcia Aymerich, D. Martínez, L.M. Braun, M. Mendez, M. Jerrett, D. Rodriguez, A. de Nazelle, M. Nieuwenhuijsen. Objective correlates and determinants of bicycle commuting propensity in an urban environment. *Transportation Research Part D: Transport and Environment*, 40 (2015), pp. 132-143, 10.1016/j.trd.2015.07.004

COLIBI, COLIPED. European bicycle market, 2014 edition, industry & market profile (2013 statistics)

COLIBI – European Bicycle Manufacturers Organization; COLIPED – Association of the European Two-Wheeler Parts' and Accessories' Industry (2014). Consulté le 22 mai 2016 à l'adresse **:** http://raivereniging.nl/ecm/?id=workspace://SpacesStore/2dcf4ea4-c647-4303-95a8-ac0045f8448b

M. Cools**.** Transport et mobilité urbaine**.** Notes de cours non publiées, ULg Faculté des Sciences Appliquées, année académique 2015–2016 (2015)

A. Cooper, A. Page, L. Foster, D. Qahwaj. Commuting to school: Are children who walk more physically active? American Journal of Preventive Medicine, 25 (4) (2003), pp. 273-276

E. Cornelis, M. Hubert, P. Huynen, K. Lebrun, G. Patriarche, A. De Witte, …, F. Walle. La Mobilité en Belgique en 2010: Résultats de l'Enquête BELDAM. Consulté à l'adresse : http://www.mobilit.fgov.be/Applications/Internet/beldamwww.nsf/Rapport_final.pdf?Openfileresource (2012)

Decathlon. (n.d.-a). Vélo de ville [Catalogue en ligne]. Consulté le 11 avril 2016 à l'adresse http://www.decathlon.be/C-409900-velo-de-ville.

Decathlon. (n.d.-b). Vélo électrique [Catalogue en ligne]. Consulté le 11 avril 2016 à l'adresse http://www.decathlon.be/C-733379-velo-electrique.

J. Dekoster, U. Schollaer. Cycling: The way ahead for towns and cities. Office for Official Publications of the European Communities, Luxembourg (1999)

J. Dill, G. Rose. Electric bikes and transportation policy: Insights from early adopters. *Transportation Research Record*, 2314 (2012), pp. 1-6, 10.3141/2314-01

R. Dober. Campus landscape. Wiley, New York (2000)

M. Dozza, G.F. Bianchi Piccinini, J. Werneke. Using naturalistic data to assess e-cyclist behavior. Transportation Research Part F: Traffic Psychology and Behaviour. (2015), 10.1016/j.trf.2015.04.003

European Commission. EU transport in figures: Statisticalpocketbook 2012. EC – European Commission. Consulté le 22 mai 2016 à l'adresse : http://ec.europa.eu/transport/facts-fundings/statistics/doc/2012/pocketbook2012.pdf (2012)

European Commission. Road transport – A change of gear. EC – European Commission. Consulté le 22 mai 2016 à l'adresse :http://ec.europa.eu/transport/modes/road/doc/broch-road-transport_en.pdf (2012)

M. Figueroa, O. Lah, L.M. Fulton, A. McKinnon, G. Tiwari. Energy for transport. *Annual Review of Environment and Resources*, 39 (1) (2014), pp. 295-325, 10.1146/annurev-environ-031913-100450

L.D. Frank, M.A. Andresen, T.L. Schmid. Obesity relationships with community design, physical activity, and time spent in cars. *American Journal of Preventive Medicine*, 27 (2) (2004), pp. 87-96

B. Gojanovic, J. Welker, K. Iglesias, C. Daucourt, G. Gremion. Electric bicycles as a new active transportation modality to promote health. *Medicine and Science in Sports and Exercice*, 43 (11) (2011), pp. 2204-2210

GRACQ. Statistiques mobilité: Les Belges et le vélo. Accessed on February 2nd 2022 : https://www.gracq.org/actualites-du-velo/statistiques-mobilite-les-belges-et-le-velo

S. Hammer, L. Kamal-Chaoui, A. Robert, M. Plouin. Cities and green growth: A conceptual framework. OECD regional development working papers 2011/08, OECD Publishing (2011), 10.1787/5kg0tflmzx34-en

I. Hendriksen, L. Engbers, J. Schrijver, R. van Gijlswijk, J. Weltevreden, J. Wilting. ElektrischFietsen: Marktonderzoek en verkenningtoekomstmogelijkheden. Report KvL/B&G/2008.067. TNO Kwaliteit van Leven. Leiden, The Netherlands (2008). Consulté le 22 mai 2016 à l'adresse : http://www.fietsberaad.nl/library/repository/bestanden/Rapport%20KvL-B&G-2008-067%20compleet.pdf

F. Héran. Vélo et politique globale de déplacements durables. Consulté à le 11 avril 2016 l'adresse : http://www.predit.prd.fr/predit4/documentFo.fo?cmd=visualize&inCd (2012)

IEA (International Energy Agency). Transport, energy and CO2: Moving toward sustainability. Paris, France (2009)

S. Ji, C.R. Cherry, M.J. Bechle, Y. Wu, J.D. Marshall. Electric vehicles in China: Emissions and health impacts. *Environmental Science & Technology*, 46 (2012), pp. 2018-2024

S. Ji, C.R. Cherry, L.D. Han, D.A. Jordan. Electric bike sharing: Simulation of user demand and system availability. *Journal of Cleaner Production*, 85 (2014), pp. 250-257, 10.1016/j.jclepro.2013.09.024

M. Johnson, G. Rose. Electric bikes – Cycling in the New World City: An investigation of Australian electric bicycle owners and the decision making process for purchase. *Australasian transport research forum 2013*, 2–4 October 2013. Brisbane, Australia (2013)

S. Kahn Ribeiro, S. Kobayashi. Transport and its infrastructure

B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (Eds.), Climate change 2007: Mitigation. Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change, Cambridge University Press, Cambridge, UK and New York, NY (2007)

KairosWirkungsforschung und Entwicklung. Landrad – NeueMobilitätfür die Alltagsmobilität in Vorarlberg. Endbericht, Bregenz. Consulté le 22 mai 2016 à l'adresse : http://landrad.at/fileadmin/downloads/110103_bericht_landrad.pdf (2010)

J.D.G. Kooijman, J.P. Meijaard, J.M. Papadopoulos, A. Ruina, A.L. Schwab. A bicycle can be self-stable without gyroscopic or caster effects. *Science*, 332 (6027) (2011), pp. 339-342

B.C. Langford, J. Chen, C.R. Cherry. Risky riding naturalistic methods comparing safety behavior from conventional bicycle riders and electric bike riders. *Accident Analysis & Prevention*, 82 (2015), pp. 220-226, 10.1016/j.aap.2015.05.016

Le Vif/L''Express. De plus en plus d'embouteillages à Bruxelles, Liège et Charleroi. 22 mars. Consulté le 14 avril 2016 à l'adresse http://www.levif.be/actualite/belgique/de-plus-en-plus-d-embouteillages-a-bruxelles-liege-et-charleroi/article-normal-480973.html#cxrecs_s

W. Liu, J. Sang, L. Chen, J. Tian, H. Zhang, G. Olvera Palma. Life cycle assessment of lead-acid batteries used in electric bicycles in China. *Journal of Cleaner Production*, 108 (Part A) (2015), pp. 1149-1156, 10.1016/j.jclepro.2015.07.026

Lorenzo Stefani. Mobilité et écologie: Les Belges sont pétris de bonnes intentions. https://www.touring.be/fr/presse/mobilite-ecologie-belges-sont-petris-bonnes-intentions (2019) (accessed on February 2nd 2022)

J. Louis, J. Brisswalter, C. Morio, C. Barla, J.-J. Temprado. The electrically assisted bicycle: An alternative way to promote physical activity. *American Journal of Physical Medicine & Rehabilitation*, 91 (2012), pp. 931-940

J. MacArthur, J. Dill, M. Person. E-bikes in the North America: Results from an online survey. Report numer 14-4885. *93rd Annual meeting of the Transportation Research Board*, 12–16 January 2014. Washington, DC, USA (2014)

A.-F. Marique, S. Reiter. A method for evaluating transport energy consumption in suburban areas. Environmental Impact Assessment Review, 33 (2012), pp. 1-6

R. Pate, M. Pratt, S. Blair, W. Haskell, C. Macera, C. Bouchard, …, J. Wilmore. Physical activity and public health: A recommendation from the centers for disease control and prevention and the American college of sports medicine. *Journal of the American Medical Association*, 273 (5) (1995), pp. 402-407

C. Pauwels, P. Andries. Diagnostic des Déplacements Domicile - Lieu de Travail 2014. SPF Mobilité et Transports, Bruxelles (2016)

N. Popovich, E. Gordon, Z. Shao, Y. Xing, Y. Wang, S. Handy. Experiences oflectric bicycle users in the Sacramento, California area. *Travel Behaviour and Society*, 1 (2) (2014), pp. 37-44, 10.1016/j.tbs.2013.10.006

P. Rietveld, V. Daniel. Determinants of bicycle use: Do municipal policies matter? *Transportation Research Part A: Policy and Practice*, 38 (2004), pp. 531-550

A. Roetynck. PRESTO cycling policy guide: Electric bicycles. Consulté à l'adresse : https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/presto_policy_guide_electric_bicycles_en.pdf (2010)

G. Rose. E-bikes and urban transportation: Emerging issues and unresolved questions. Transportation, 39 (2012), pp. 81-96

L. Rotaris, R. Danielis. Commuting to college: The effectiveness and social efficiency of transportation demand management policies. *Transport Policy*, 44 (2015), pp. 158-168

G. Santos, H. Maoh, D. Potoglou, T. von Brunn. Factors influencing modal split of commuting journeys in medium-size European cities. *Journal of Transport Geography*, 30 (2013), pp. 127-137, 10.1016/j.jtrangeo.2013.04.005

T. Shannon, B. Giles-Corti, T. Pikora, M. Bulsara, T. Shilton, F. Bull. Active commuting in a university setting: Assessing commuting habits and potential for modal change. *Transport Policy*, 13 (3) (2006), pp. 240-253, 10.1016/j.tranpol.2005.11.002

D. Shoup. The high cost of free parking. *Journal of Planning Education and Research*, 17 (1) (1997), pp. 3-20

M. Simons, E. Van Es, I. Hendriksen. Electrically assisted cycling: A new mode for meeting physical activity guidelines. *Medicine & Science in Sports & Exercise*, 41 (11) (2009), pp. 2097-2102

J. Theurel, A. Theurel, R. Lepers. Physiological and cognitive responses when riding an electrically assisted bicycle versus a classical bicycle. *Ergonomics*, 55 (7) (2012), pp. 773-781

J.-M. Timmermans, P. Lataire, G. Maggetto, J. Cappelle. De elektrischefietsalsduurzamemobiliteit in steden. Unknown Journal (2003) : https://cris.cumulus.vub.ac.be/portal/en/publications/de-elektrische-fiets-als-duurzame-mobiliteit-in-steden%286283a5db-a4ff-41a9-9c7c-88c118ba114c%29.html

R. Tolley. Green campuses: Cutting the environmental cost of commuting. Journal of Transport Geography, 4 (3) (1996), pp. 213-217

United Cities and Local Governments, and Cities for Mobility, Agenda 21 for urban mobility. City of Stuttgart, Stuttgart (2009)

O. Van Boggelen, J. Van Oijen, R. Lankhuijzen. Feiten Over de Elektrische. Fietsberaad, Utrecht (2013)

T. van der Kuijp, L. Huang, C. Cherry. Health hazards of China's lead-acid battery industry: A review of its market drivers, production processes, and health impacts. Environmental Health, 12 (1) (2013), pp. 1-10

G. Vandenbulcke, C. Dujardin, I. Thomas, B. de Geus, B. Degraeuwe, R. Meeusen, L.I. Panis Cycle commuting in Belgium: Spatial determinants and 're-cycling' strategies. *Transportation Research Part A: Policy and Practice*, 45 (2) (2011), pp. 118-137, 10.1016/j.tra.2010.11.004

G. Vandenbulcke, I. Thomas, B. de Geus, B. Degraeuwe, R. Torfs, R. Meeusen, L. IntPanis. Mapping bicycle use and the risk of accidents for commuters who cycle to work in Belgium. Transport Policy, 16 (2) (2009), pp. 77-87, 10.1016/j.tranpol.2009.03.004

A. Verhetsel, I. Thomas, E. Van Hecke, M. Beelen. Monografie van het Woonwerkverkeer in Belgïe. *Belgian Science Policy and FPS Mobility and Transports*, Brussels (2007)

T. Weber, G. Scaramuzza, K.-U. Schmitt. Evaluation of e-bike accidents in Switzerland. Accident Analysis & Prevention, 73 (2014), pp. 47-52, 10.1016/j.aap.2014.07.020

J. Weinert, E. VanGelder. Light traction: Batteries. *Encyclopedia of electrochemical power sources*, Elsevier, Amsterdam (2009), pp. 292-301. Consultéàl'adresse : http://www.sciencedirect.com/science/article/pii/B9780444527455003749

J.X. Weinert, C. Ma, C.R. Cherry. The transition to electric bikes in China: History and key reasons for rapid growth. *Transportation*, 34 (3) (2007), pp. 301-318

J.X. Weinert, C. Ma, X. Yang, C.R. Cherry. Electric two-wheelers in China: Effect on travel behavior, mode shift, and user safety – Perceptions in a medium-sized city. *Transportation Research Record: Journal of the Transportation Research Board*, 2038 (2007), pp. 62-68

J.X. Weinert, J. Ogden, D. Sperling, A. Burke. The future of electric two-wheelers and electric vehicles in China. *Energy Policy*, 36 (7) (2008), pp. 2544-2555

M. Weiss, P. Dekker, A. Moro, H. Scholz, M.K. Patel. On the electrification of road transportation – A review of the environmental, economic, and social performance of electric two-wheelers. *Transportation Research Part D: Transport and Environment*, 41 (2015), pp. 348-366, 10.1016/j.trd.2015.09.007

L. Whitmarsh, J. Kohler. Climate change and cars in the EU: The roles of auto firms, consumers, and policy in responding to global environmental change. *Cambridge Journal of Regions, Economy and Society*, 3 (3) (2010), pp. 427-441, 10.1093/cjres/rsq008

B. Wilkinson. Nonmotorized transportation: The forgotten modes. *Annals of the American Academy of Political and Social Sciences*, 553 (1997), pp. 87-93

M. Winters, G. Davidson, D. Kao, K. Teschke. Motivators and deterrents of bicycling: Comparing influences on decisions to ride. *Transportation*, 38 (1) (2010), pp. 153-168, 10.1007/s11116-010-9284-y

A. Wolf, S. Seebauer. Technology adoption of electric bicycles: A survey among early adopters. *Transportation Research Part A: Policy and Practice*, 69 (2014), pp. 196-211, 10.1016/j.tra.2014.08.007

J. Woodcock, D. Banister, P. Edwards, A.M. Prentice, I. Roberts. Energy and transport. *The Lancet*, 370 (2007), pp. 1078-1088

D. Zhen, Y. Deng, Y. Luo. Rising of electric bicycle in China. Journal of Iron and Steel Research, International, 13 (Supplement 1) (2006), pp. 378-382, 10.1016/S1006-706X(08)60213-7